TECHNICAL NOTES.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

No. 85.

AIR FORCE AND THREE MOMENTS FOR F-5-L SEAPLANE

By the Aeronautics Staff,
Construction Department, Navy Yard,
Washington, D. C.

Prepared under the direction of the
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Introduction.- A model of the F-5-L seaplane was made, verified, and tested at 40 miles an hour in the 8' x 8' tunnel for lift and drag, also for pitching, yawing and rolling moments. Subsequently, the yawing moment test was repeated with a modified fin. The results are reported without VL scale correction.

Model.- Figures 1, 12 and 13 give the general appearance and chief dimensions of the model. For subsequent investigation of yawing moments on the original model, it was found desirable to replace the fin of the tail unit by one of approximately 50% greater area and with the rudder-balancing surface omitted. The altered fin is shown by dotted lines in Figures 1 and 12.

Apparatus.- The lift and drag were measured as usual on the Eiffel balance; the pitching and yawing moments on the torsion balance; the rolling moments on a special apparatus improvised for the purpose as shown in Figures 2 and 14. In the latter device, the model is supported from the shank of the torsion balance by means of an emery knife edge which permits it to roll through very small angles without material resistance. The knife edge is parallel to the assumed thrust line and passes through a

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* This report is a slightly revised form of the unpublished Report No. 118, Construction Department, Navy Yard, Washington, D. C.

point representing the center of gravity of the seaplane. The
moment is measured by means of a small double-platform scale
from which a fine steel wire is run downwardly through the ceil-
ing of the wind tunnel, and secured to one wing of the model, con-
tinuing to a point near the floor of the tunnel, where it is at-
tached to a shielded weight which keeps it taut. During the test,
the rolling displacements of the model were just large enough to
permit of reading the indications of the platform balance.

Pitching Moments.- Figure 12 gives the line of resultant
air force on the model with elevator neutral; Table I and Figure
3 give, with elevator neutral, 10° up and 10° down, the pitching
moments about the transverse centroidal axis, shown in Figure 12.
Both figures and the table show that the seaplane with neutral
elevator balances at 9° angle of attack about the center of grav-
ity, and, for angles between 0° and 13°, possesses sufficient in-
herent stability, though unstable above 13°. The diagram at the
bottom of Figure 12 shows the center of pressure travel on a
plane through the center of gravity parallel to the thrust line.

Figure 3 shows that, for the full scale seaplane, pivoted
about its transverse centroidal axis at 40 miles an hour, the
shift of the center pressure is nearly one inch per degree change
of elevator. The same is indicated by the moment diagram taken
together with the lift diagram. Figure 3 furthermore shows that
at 9° angle of attack the change of pitching moment for 1° change
of angle of attack of the seaplane is 570 pound-feet, and for 1°

angle of elevator is 340 pound-feet. This latter moment remains nearly constant through the usual angles of flight, whereas the moment for change of angle of attack of the seaplane varies considerably.

Yawing Moments with original fin.- Figures 4 and 5 and Tables II and III present the yawing moments; first with the hull neutral and rudder turned; then with the hull yawed and the rudder neutral to it. Under both conditions, the seaplane possesses fair directional qualities at all settings from zero to 20°, positive and negative. Figure 4 indicates that the moment on the rudder is almost exactly proportional to the angle of attack of the rudder.

Yawing Moments with modified fin.- Figures 10 and 11 and Tables II and III show, for increased fin surface, the yawing moments with hull neutral and rudder turned, and for hull yawed and rudder neutral to it. This enlarged fin improves the directional quality for the same rudder moment. The moments about the hinge of the rudder are increased by the removal of the balancing surface, but as these moments are small for usual angles of rudder movement, it appears more desirable to use this area as a part of the fixed fin for directional stabilizing.

The moment for both the original and the modified rudder is sufficient, though not ample, to steer the seaplane on a straight level course with one engine stopped and the other maintaining a flight speed of 67 miles an hour. For at this speed the thrust

of the one propeller is 1700 pounds, which gives a yawing moment of 10,200 pound-feet, or that of the rudder at about 20° angle of attack.

Rolling Moments.- Figures 6 and 7 give the rolling moments on the seaplane: first, with the hull axis parallel to the wind and the rudder set at various angles of attack; then with the ailerons neutral and the hull yawed through various angles. These show that with neutral ailerons the rolling moment increases uniformly with yaw from 0° to 20°; also that without yaw it increases continuously with aileron turning from 0° to 20°.

Lift and Drag.- Figure 8 and Tables I and IV, giving the lift, drag and lift/drag, disclose characteristics resembling those for the R.A.F.6 aerofoil. The lift reaches its maximum at about 16° angle of attack. The maximum lift/drag is 8.1 at 9° angle of attack and is not well sustained. The rapid decline in the lift/drag at 16° is due almost entirely to the rapid increase of drag. This value of the maximum lift/drag is not great considering the large aspect ratio. It may be recalled that the Burgess seaplane scout and Curtis HA seaplane had lift/drag ratios respectively equal to 8.7 and 8.1, though the aspect ratio was less than for the present model. The T·B seaplane with an aspect ratio of about 7 discloses a maximum lift/drag ratio of 9.4. In none of these, however, were the models, in their minor details of structure, geometrically similar to the full scale seaplane.

Performance. - Figure 9 shows that the seaplane weighing 13,500 pounds can be sustained at slightly over 55 miles per hour and with 800 horsepower actuating propellers of 75% efficiency, can attain a speed of 96 miles per hour. Owing, however, to the rapid decrease of lift at the higher angles of attack, it would seem best not to navigate at speeds much below 60 miles per hour. In standard air the seaplane should be able to climb at the rate of 185 feet per minute at a speed of 65 miles an hour, and 375 feet per minute at 85 miles an hour.

Table I.

Model

F 5 L seaplane
V = 40 mi/hr.
$V^2 \frac{\rho}{2} = q = 4.1$ lbs/ sq.ft.

S = 2.42 ft.
S_q = 9.9 lbs.
Max.span = 4.323 ft.
Scale of model, 1:24
Area of elevators, 0.096 sq.ft.
Span of elevators, .8125 ft.

Angle of Attack	Lift in pounds			Drag in pounds			Pitching moment in lbs.in.		
	Elevator			Elevator			Elevator		
	10° up	0°	10° down	10° up	0°	10° down	10° up	0°	10° down
− 6	−3.605	−3.289	−3.017	1.208	1.205	1.147	6.200	2.171	− .307
− 3	−1.144	−0.669	−0.347	0.902	0.862	0.854	5.925	2.188	− .748
− 1	+0.712	1.068	1.380	0.779	0.742	0.722	---	---	---
0.	1.525	1.897	2.233	0.735	0.707	0.698	5.653	2.283	− .525
1	2.377	2.755	3.076	0.707	0.690	0.696	---	---	---
2	3.188	3.570	3.898	0.707	0.694	0.712	5.548	2.290	− .793
3	3.970	4.355	4.730	0.728	0.717	0.730	---	---	---
4	4.750	5.125	5.470	0.764	0.754	0.792	5.050	1.914	−1.214
6	6.275	6.665	6.983	0.866	0.870	0.909	4.690	1.370	−1.619
8	7.750	8.150	8.510	1.004	1.015	1.063	3.671	.329	−2.573
10	9.220	9.582	9.937	1.175	1.187	1.240	2.134	−.580	−3.503
12	10.520	10.850	11.195	1.377	1.397	1.445	.759	−1.641	−3.835
14	11.550	11.855	12.215	1.650	1.694	1.748	.817	−1.916	−4.812
16	12.050	12.375	12.730	2.214	2.322	2.411	2.204	− .378	−4.360

Full size.

F 5 L seaplane
V = 40 mi/hr.
$V^2 \frac{\rho}{2} = q = 41$ lbs/ sq.ft.

S = 1394 sq.ft.
S_q = 5715.4 lbs.
Max.span = 103' 9¼"
Scale − full size
Area of elevators, 56 sq.ft.
Span of elevators, 19' 6".

Angle of Attack	10° up	0°	10° down	10° up	0°	10° down	10° up	0°	10° down
− 6	−2076.0	−1895.0	−1737.5	696.0	694.5	661.0	7143	2500	− 930
− 3	− 659.0	− 385.0	− 200.0	519.2	496.5	492.0	6825	2520	− 862
− 1	410.0	615.0	795.0	448.5	426.4	415.8	---	---	---
0	878.5	1093.0	1286.5	423.2	407.3	402.0	6510	2630	− 605
1	1369.5	1587.0	1771.0	407.3	397.5	400.9	---	---	--
2	1835.0	2056.5	2245.0	407.3	399.7	410.0	6393	2638	− 914
3	2287.0	2508.0	2724.5	419.2	413.0	420.5	---	---	---
4	2736.0	2952.0	3150.0	440.0	434.2	456.1	5820	2204	−1399
6	3615.0	3838.0	4022.0	498.8	501.0	523.5	5405	1578	−1865
8	4465.0	4695.0	4900.0	578.0	584.5	606.5	4230	379	−2965
10	5310.0	5520.0	5724.0	677.0	686.0	714.2	2460	− 668	−4035
12	6060.0	6250.0	6445.0	793.5	805.0	833.0	875	−1890	−4420
14	6655.0	6830.0	7040.0	951.0	976.0	1006.5	941	−2203	−5545
16	6940.0	7130.0	7334.0	1275.0	1337.5	1389.0	2540	− 435	−5025

Table II.

F 5 L seaplane
V = 40 mi/hr.
q = 4.1 lbs/sq.ft.
Scale of model
    1 : 24
Axis of yawing normal to thrust line, 34% of chord length aft of leading edge.

Angle of respect- ive control surface	Model pounds-inches			
	Yawing moment		Rolling moment	
	Original fin surface	Revised fin surface	Angle of yaw 0°	Angle of aileron 0°
0°	+ .09	+ .16	1.12	1.10
5°	− .65	− .58	9.22	3.81
10°	−1.39	−1.29	18.19	6.37
15°	−2.12	−2.06	25.32	8.72
20°	−2.29	−3.85	29.88	11.31

F 5 L seaplane
V = 40 mi/hr.
q = 4.1 lbs/sq.ft.
Scale : full size
Axis of yaw moment normal to thrust line, 34% of chord length aft of leading edge.

	Full size pounds-feet			
0°	+ 107	+ 184	1290	1268
5°	− 742	− 667	10630	4380
10°	−1595	−1492	20950	7340
15°	−3436	−3382	29180	10040
20°	−3324	−3392	34420	13040

Table III.

F 5 L seaplane

V = 40 mi/hr.

q = 4.1 lbs/sq.ft.

Scale of model

   1 : 24

Area of rudder

Rudder neutral to

axis of hull.

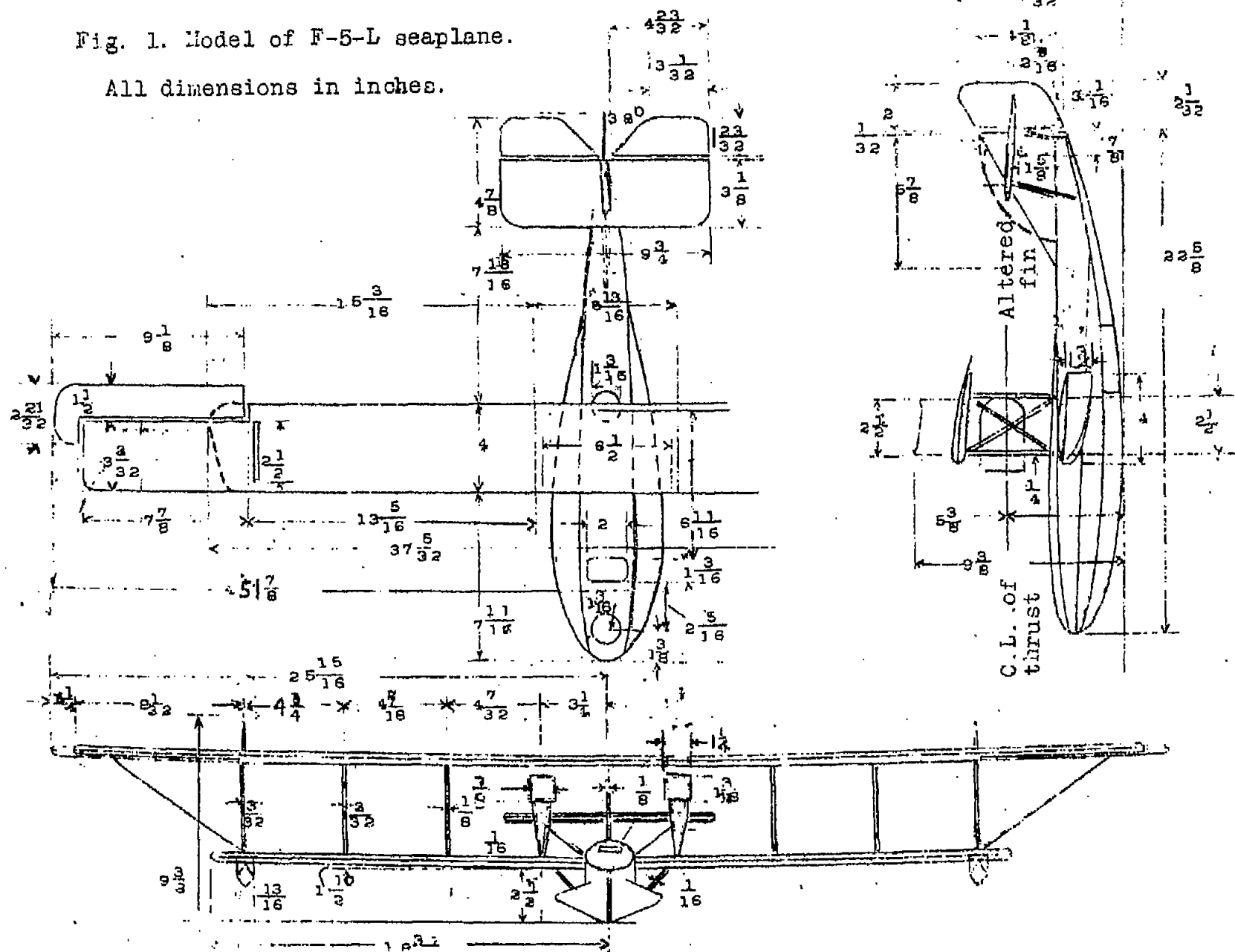| Angle of yaw	Model pounds-inches Yawing moment	
	Original fin surface	Revised fin surface
20°	− 3.40	− 4.27
18°	− 2.92	− 3.54
16°	− 2.46	− 2.93
14°	− 2.03	− 2.44
12°	− 1.63	− 1.98
10°	− 1.32	− 1.56
8°	− 1.00	− 1.13
6°	− 0.69	− .68
4°	− 0.41	− .40
2°	− 0.14	− .07
0°	+ 0.09	+ .16
−2°	0.33	.44
−4°	0.60	.79
−6°	0.88	1.07
−8°	1.20	1.47
−10°	1.52	1.83
−12°	1.89	2.38
−14°	2.28	2.92
−16°	2.70	3.39
−18°	3.15	4.03
−20°	3.60	4.58

F 5 L seaplane

V = 40 mi/hr.

q = 4.1 lbs/sq.ft.

Scale : full size

Area of rudder
33 sq.ft.

Rudder neutral to

axis of hull.

Angle of yaw	Full size pounds-feet	
20	−3918	−4920
18	−3363	−4080
16	−2834	−3380
14	−2339	−2810
12	−1878	−2280
10	−1521	−1800
8	−1152	−1302
6	−0795	− 782
4	−0476	− 465
2	−0158	− 85
0	+0107	+ 184
−2	0380	507
−4	0692	908
−6	1014	1233
−8	1382	1695
−10	1752	2110
−12	2188	3740
−14	2627	3364
−16	3111	3910
−18	3628	4645
−20	4147	5260

Table IV.

	Model		
	Lift/Drag on model in lbs.		
Angle	Elevator		
	10° up	0°	10° down
-6	-2.984	-2.729	-2.63
-3	-1.268	-.078	-.406
-1	.9139	1.439	1.911
0	2.075	2.683	3.20
1	3.362	3.992	4.42
2	4.509	5.144	5.475
3	5.453	6.074	6.479
4	6.217	6.797	6.907
6	7.246	7.661	7.682
8	7.719	8.03	8.006
10	7.847	8.072	8.014
12	7.639	7.766	7.747
14	7.000	6.988	6.988
16	5.442	5.329	5.28

F 5 L seaplane
V = 40 mi/hr.
Scale - 1:34

	Full size		
-6	-2.982	-2.730	-2.630
-3	-1.268	-0.776	-0.406
-1	+0.914	+1.439	+1.911
0	2.075	2.685	3.200
1	3.363	3.992	4.420
2	4.510	5.145	5.475
3	5.455	6.075	6.480
4	6.220	6.800	6.915
6	7.245	7.660	7.682
8	7.725	8.030	8.005
10	7.845	8.070	8.010
12	7.640	7.718	7.745
14	7.000	7.000	6.990
16	5.442	5.570	5.220

F 5 L seaplane
V = 40 mi/hr.
Scale: full size

Fig. 1. Model of F-5-L seaplane.

All dimensions in inches.

Scales Angle of attack dial

Stays Knife edge

Model

.011"
dia. wire

Stream line shield

Weight Floor of tunnel
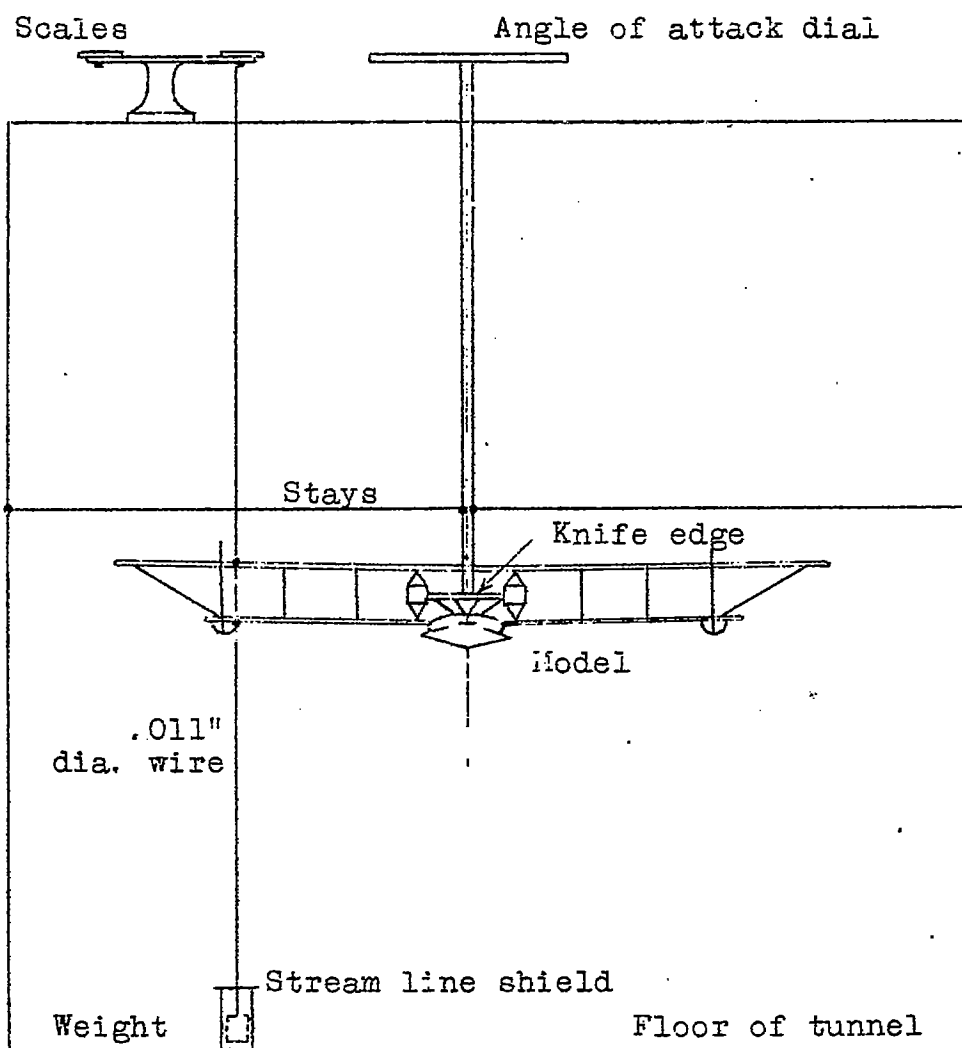
Fig. 2. Apparatus for measuring rolling moments.

W=Weight in pounds for full-size seaplane.
-U=Velocity in m.p.h. of seaplane.
θ=Inclination of longitudinal axis to the horizontal.
For reference axis for pitching moments see Fig. 12.
mM_W=Variation of pitching moment due to change of
    normal velocity for full-size seaplane.
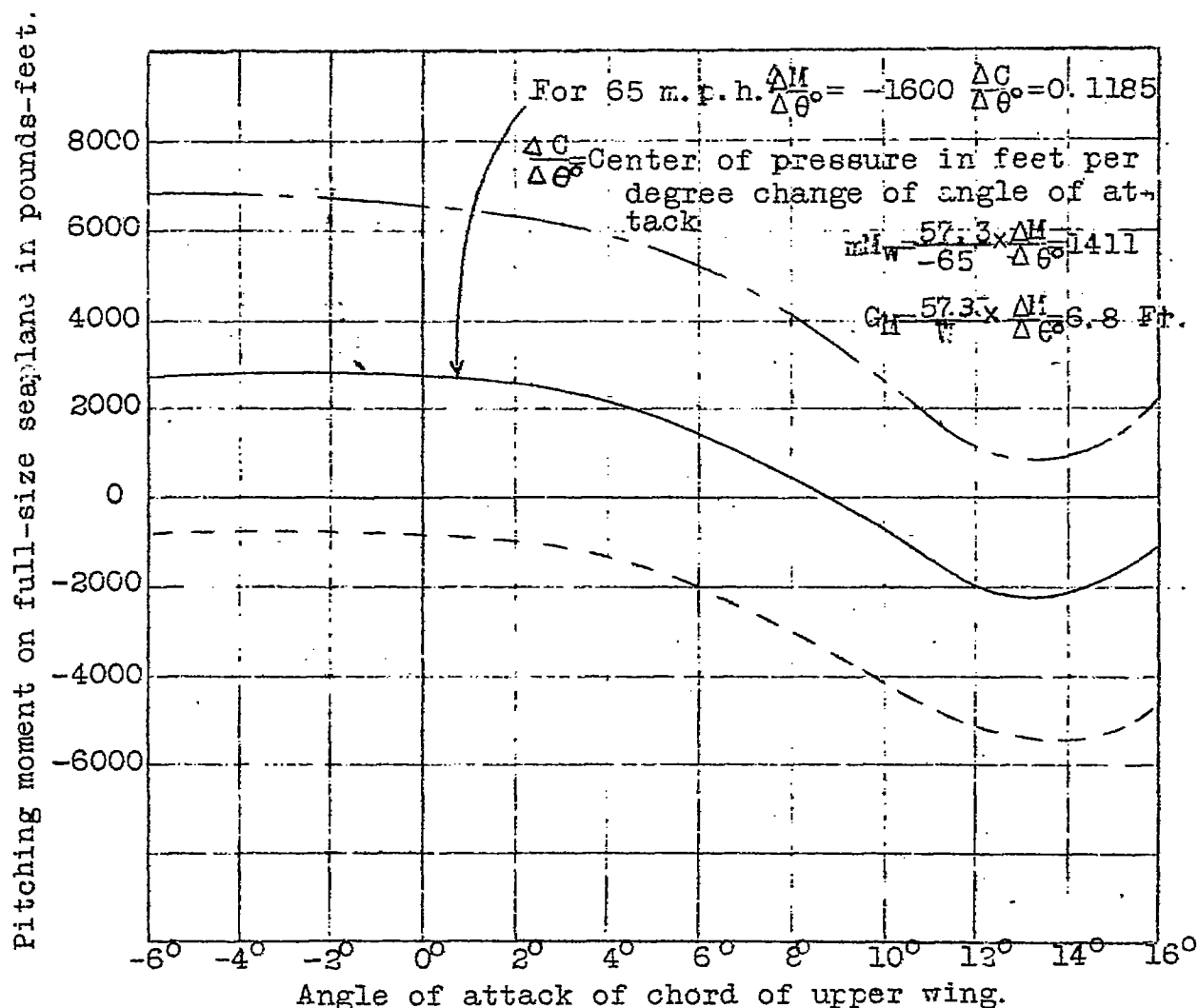G_M="Metacentric height" for full-size seaplane.

Fig. 3. Pitching moment about an assumed axis at 40 m.p.h.
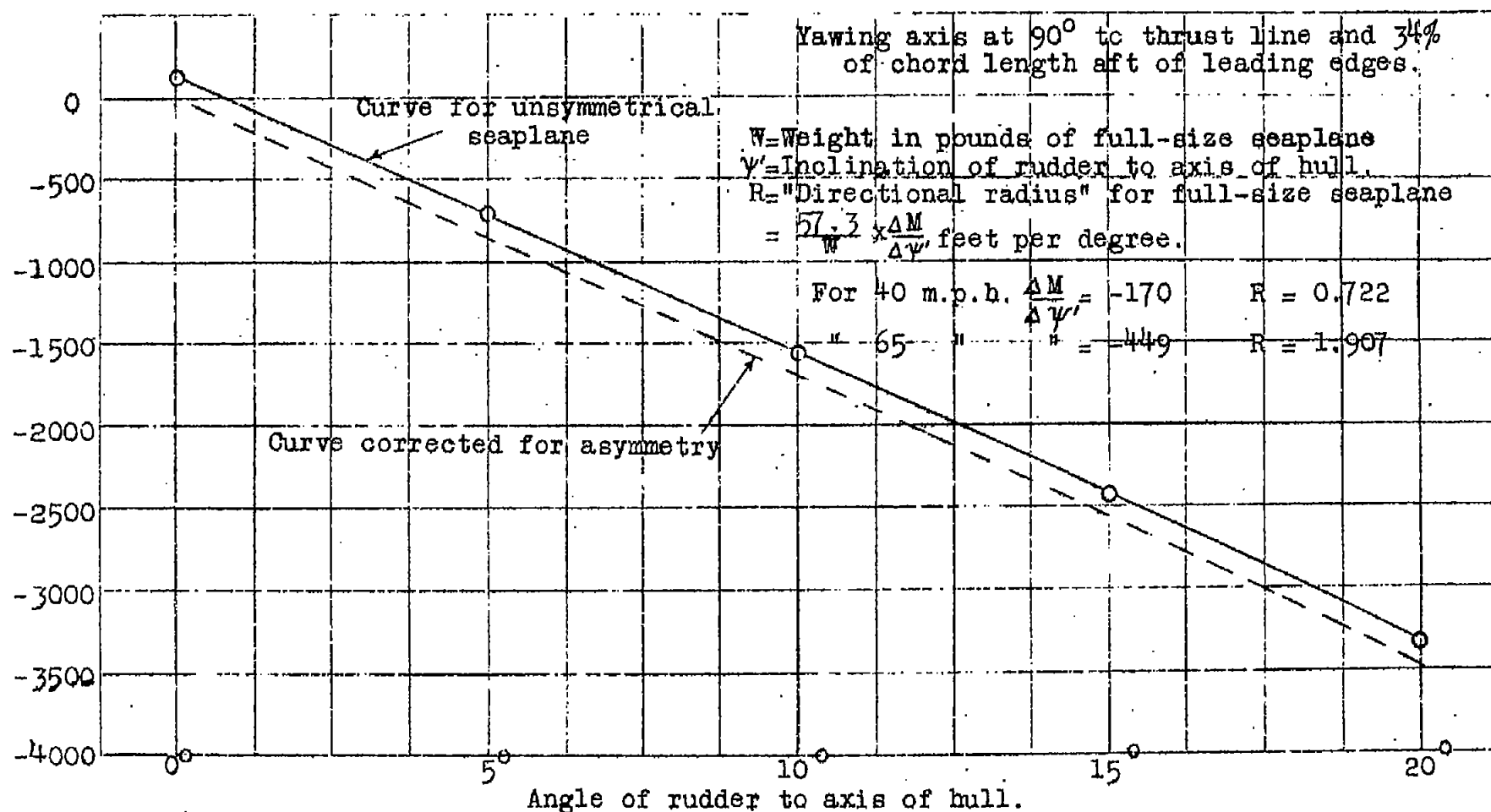
—— – —— Elevators 10° up.
——————— "   0°
– – – – – — "   10° down.

Fig. 4. Yawing moment for various rudder angles. Axis of hull parallel to wind.
Wind speed 40 m.p.h.

Yawing moment on full-size-seaplane in pound-feet.

5000
4000
3000
2000
1000
0
-1000
-2000
-3000
-4000
-5000

Curve of unsymmetrical seaplane

Curve corrected for asymmetry

Yawing axis at 90° to thrust axis
and 34% of chord length aft of leading
edges.

W=Weight in pounds of full-size seaplane,
ψ =Inclination of longitudinal axis to
relative wind.
R="Directional radius" for full-size seaplane.

$$= \frac{57.3}{W} \times \frac{\Delta M}{\Delta \psi} \text{ feet per degree.}$$

For 40 m.p.h. $\frac{\Delta M}{\Delta \psi}$ = -130   R = 0.552

"   65   "   "   = -343   R = 1.458

-20°   -15°   -10°   -5°   0°   5°   10°   15°   20°
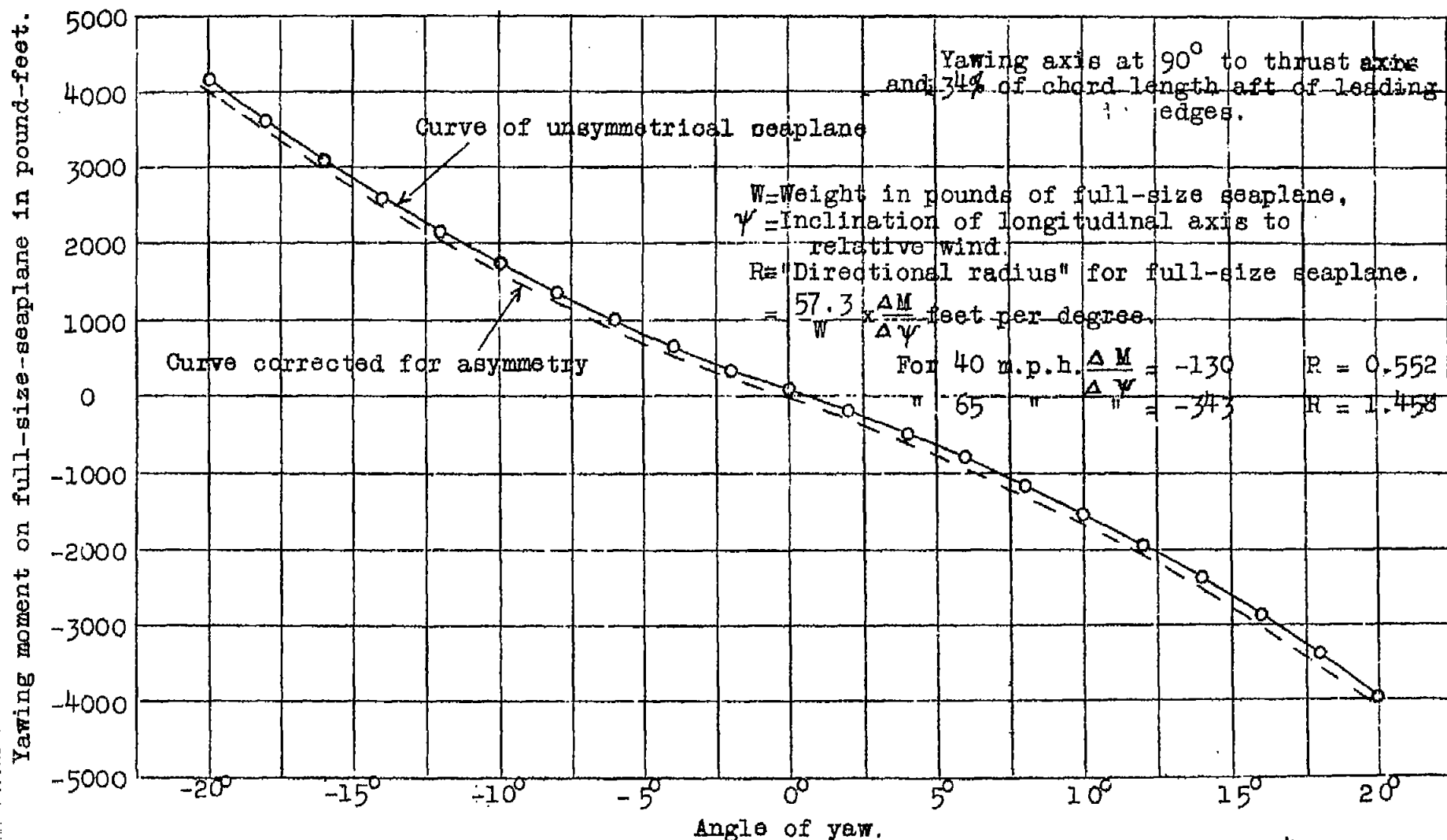
Angle of yaw.

Fig. 5. Yawing moments with hull yawed and rudder neutral to hull.   Wind speed 40 m.p.h.
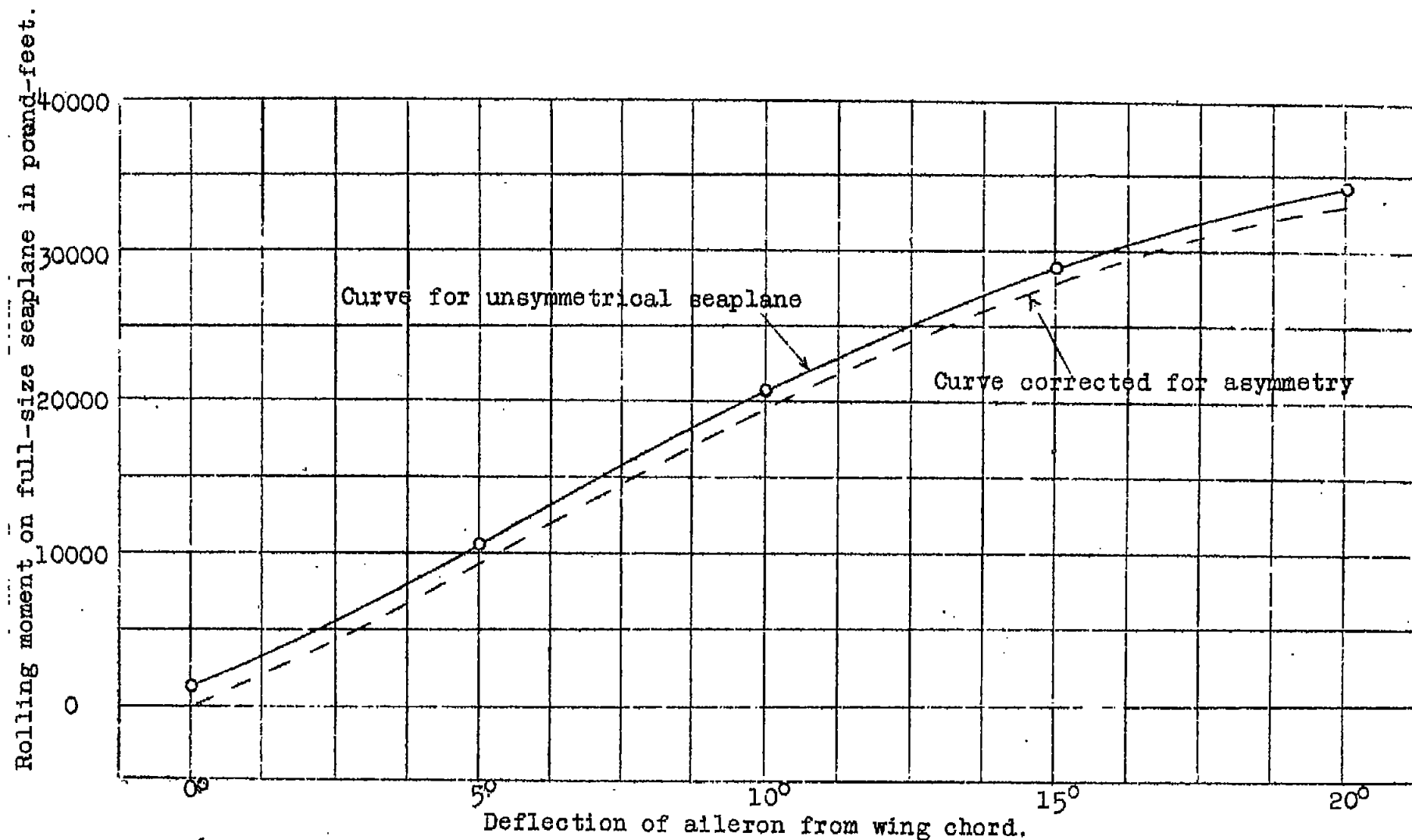
Fig. 6. Rolling moment at various positions of ailerons.   Axis of hull parallel to wind.
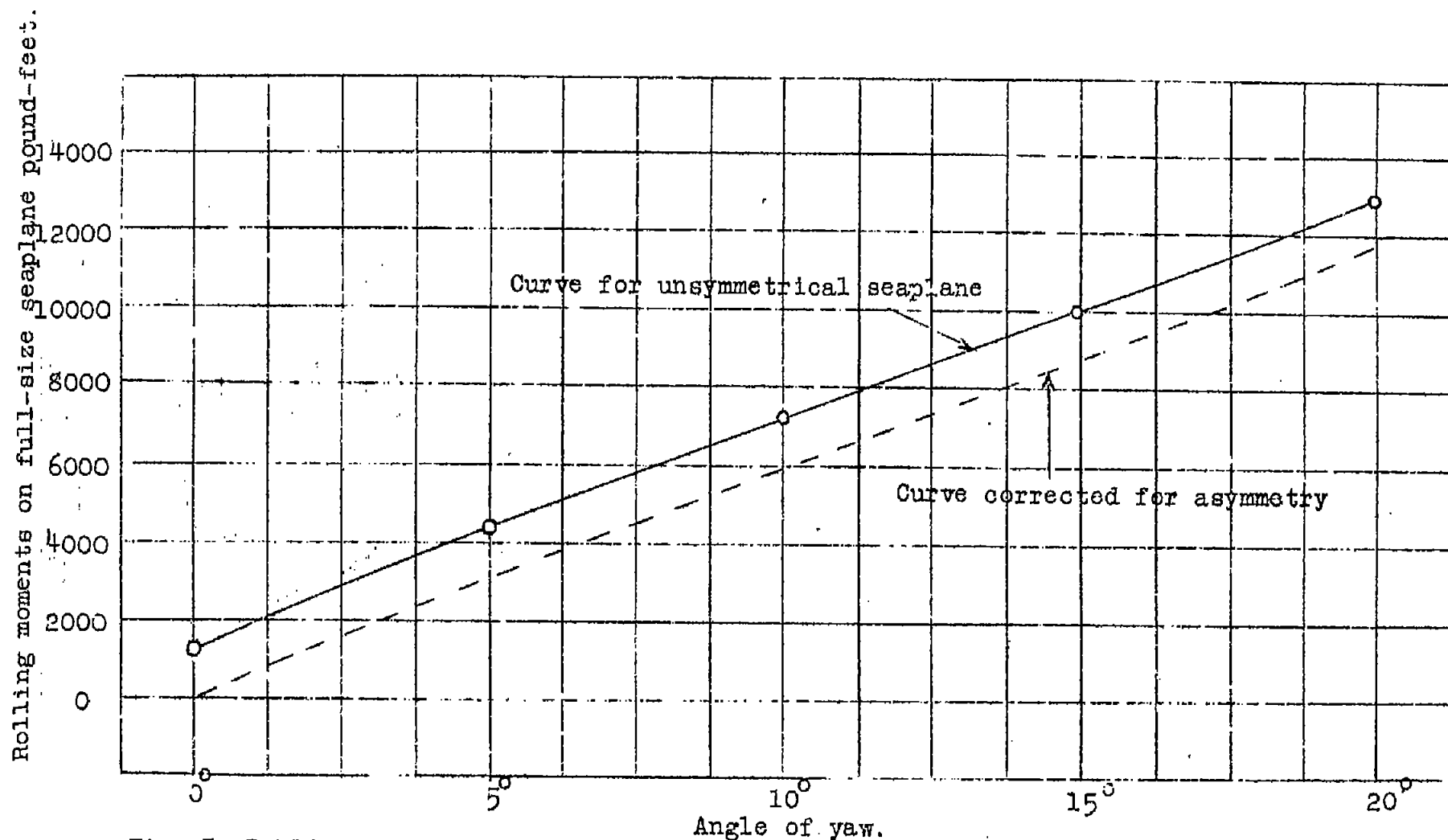Wind speed 40 m.p.h.

Fig. 7. Rolling moment at various angles of yaw with aileron neutral. Wind speed 40 m.p.h.
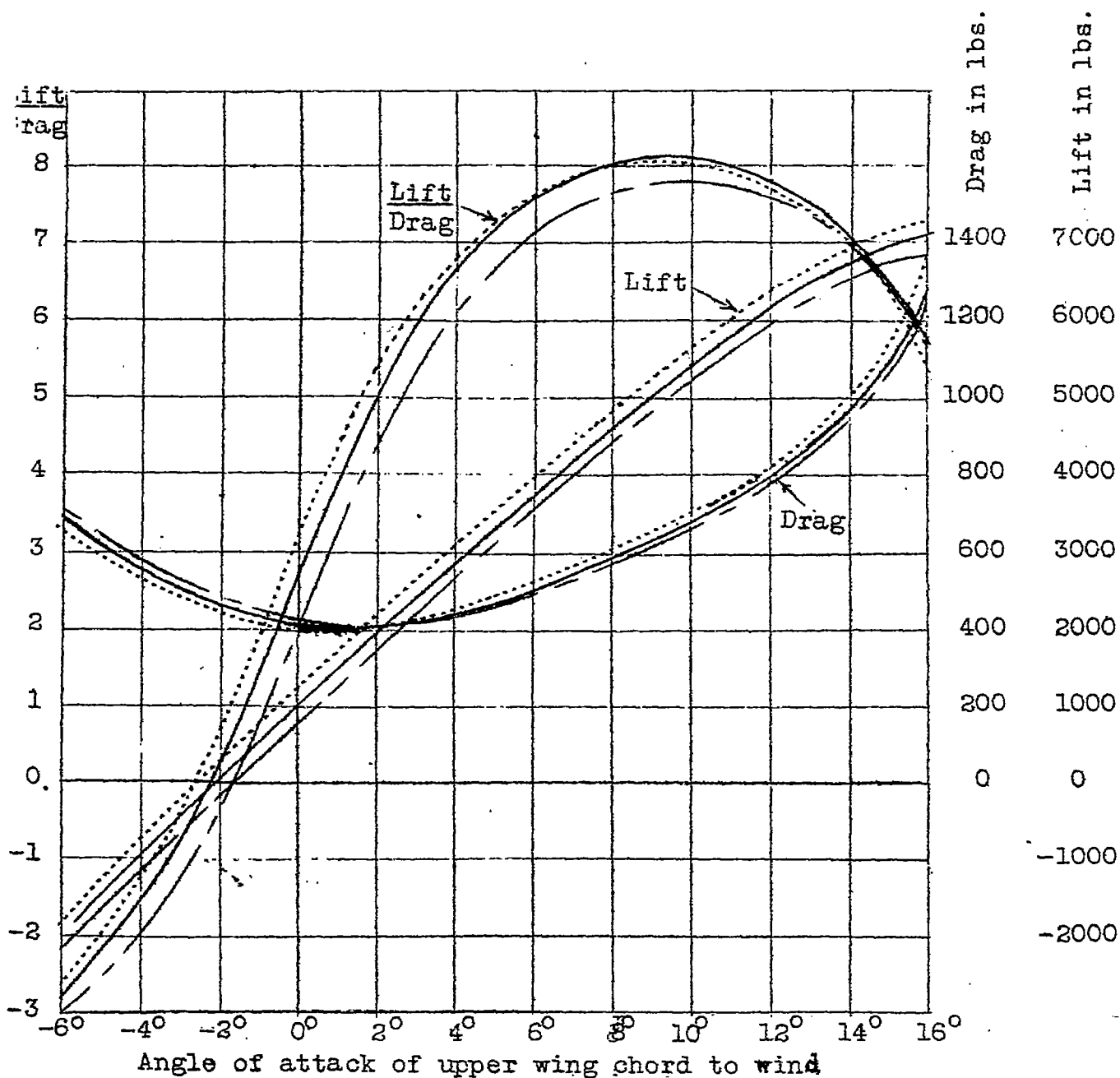
Fig. 8. Lift, drag, and $\frac{\text{lift}}{\text{drag}}$ at 40 m.p.h. on full-size seaplane.

———————————— Experiment 1 elevators at 0°

— — — — — " 2 " " 10° up.
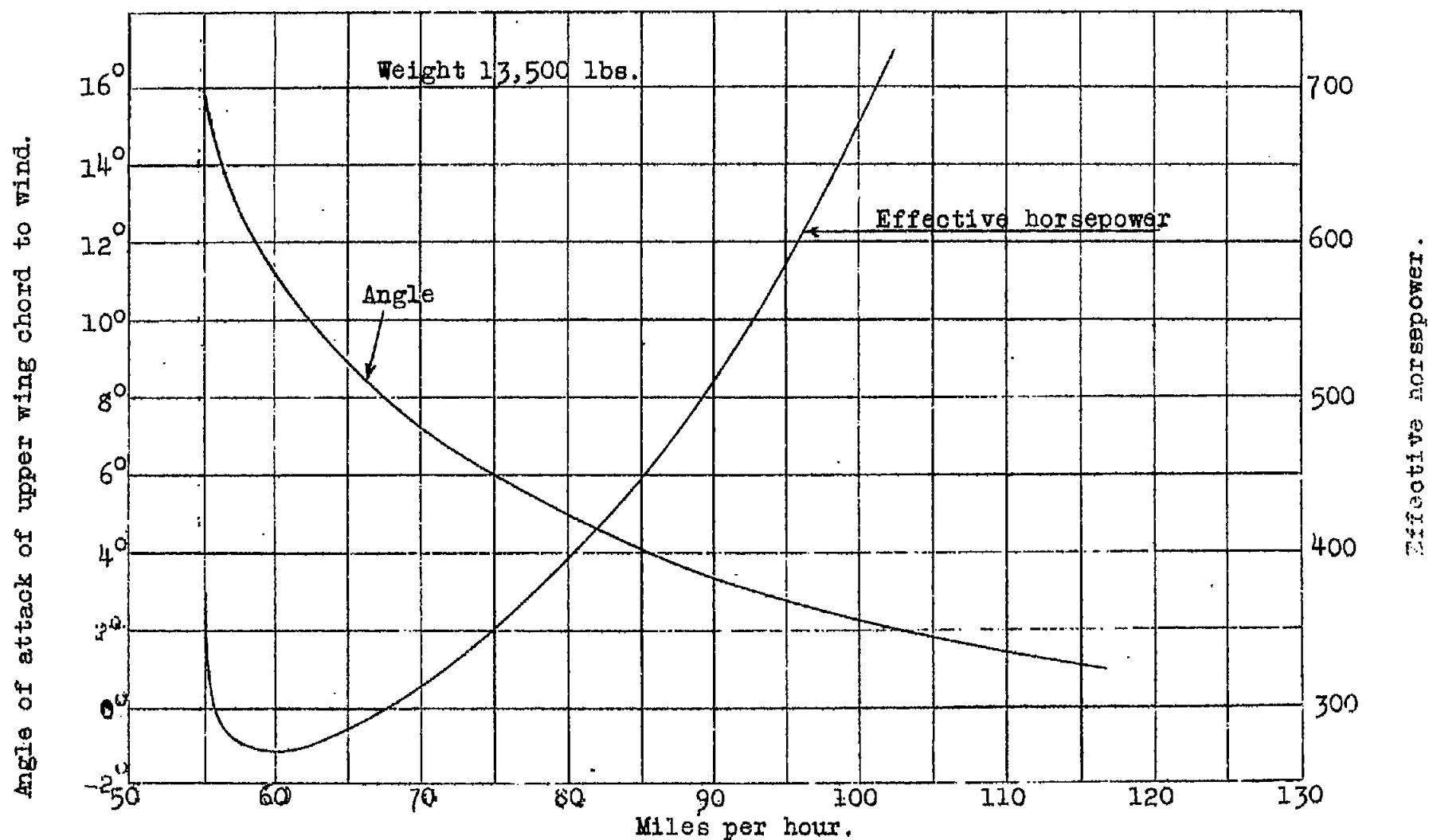
·············· " 3 " " 10° down.

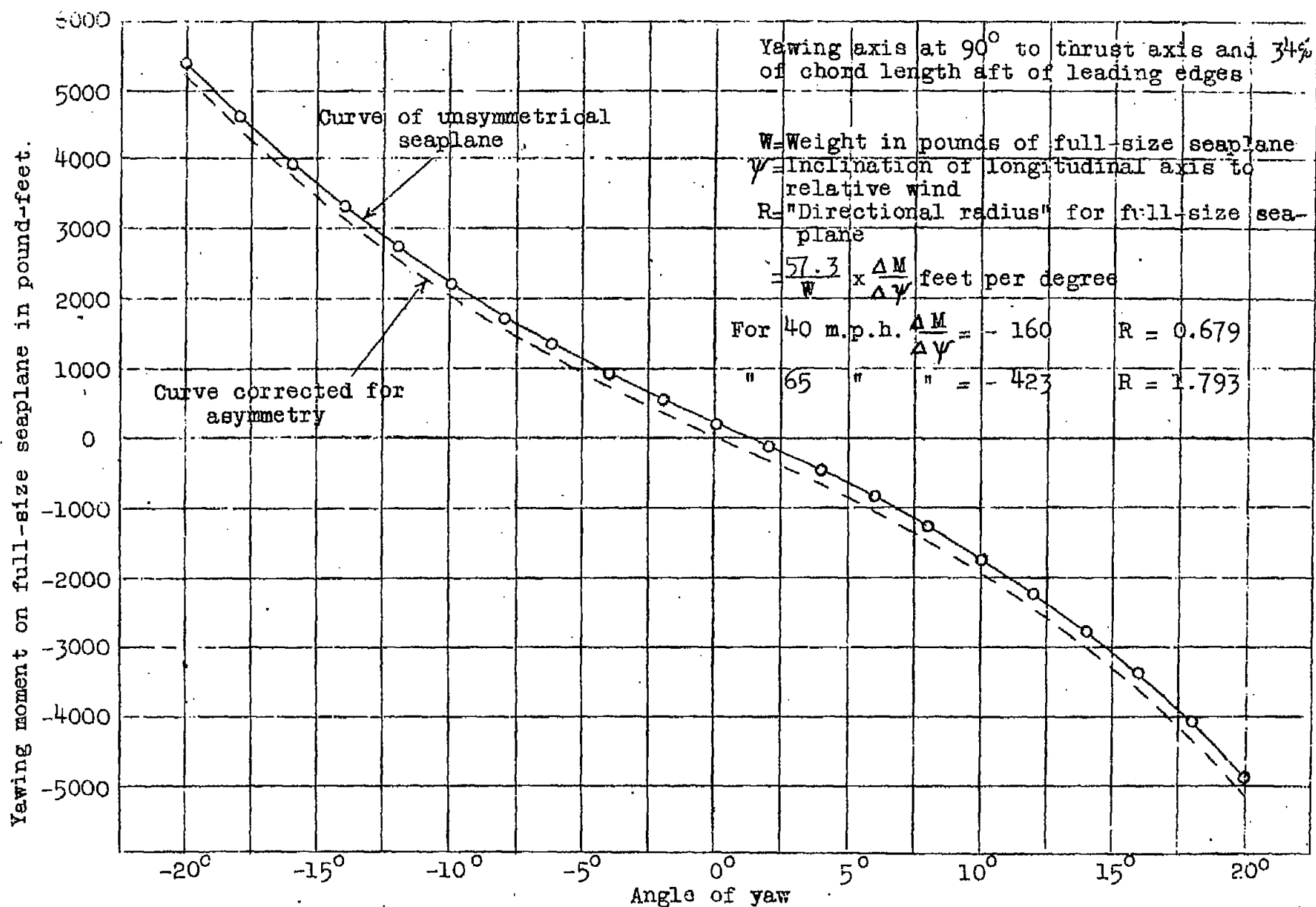Fig. 9. Effective horsepower and angle Elevators neutral.

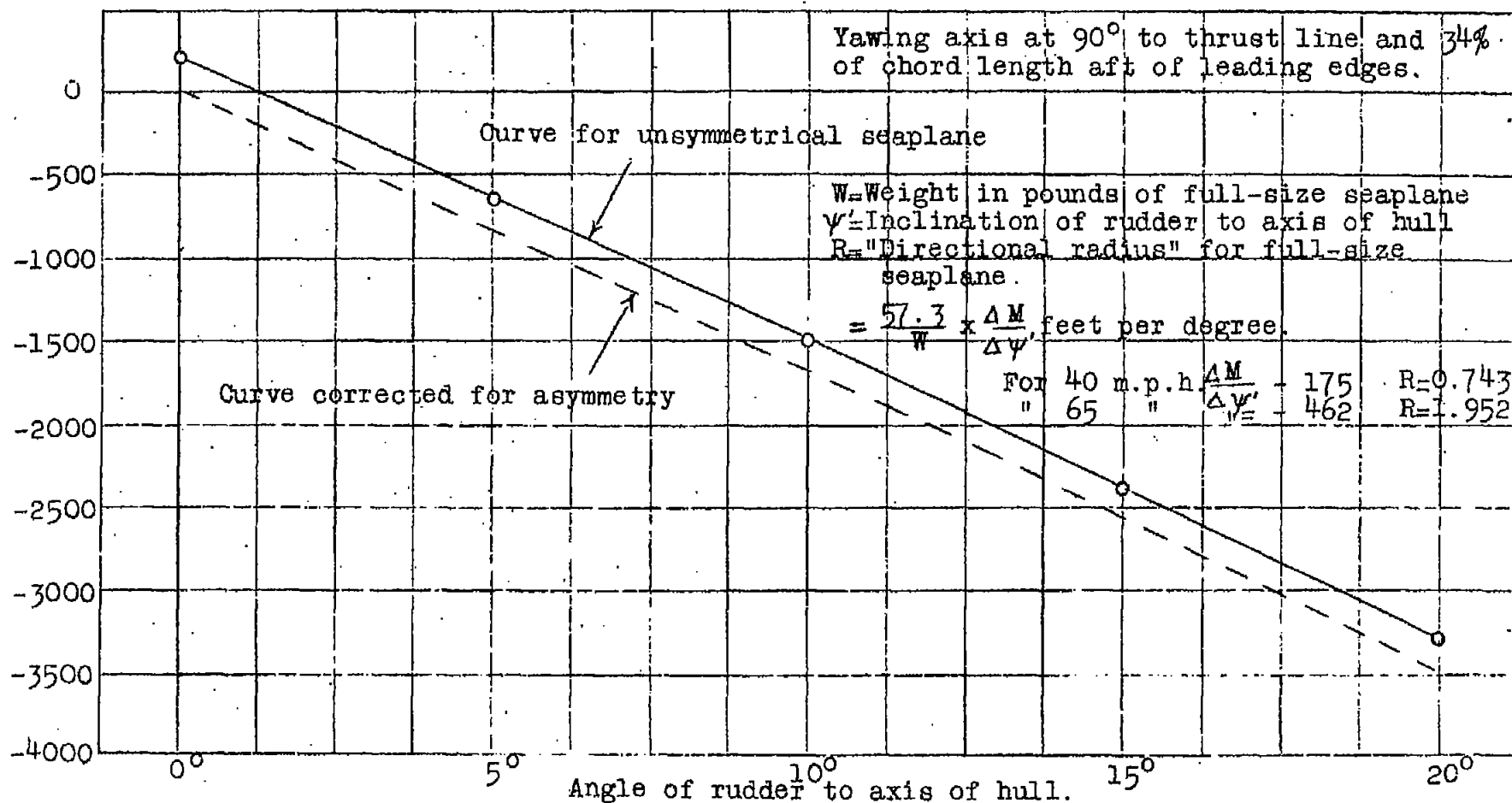Fig.10. Yawing moments with hull yawed and rudder neutral to hull. Revised fin. Wind speed 40 m.p.h.

Fig.11. Yawing moment for various rudder angles with revised fin. Axis of hull parallel to wind
Wind speed 40 m.p.h.

Yawing moment on full-size seaplane in pound-feet. (y-axis label)

Angle of rudder to axis of hull. (x-axis label)

Yawing axis at 90° to thrust line and 34% of chord length aft of leading edges.

Curve for unsymmetrical seaplane

W=Weight in pounds of full-size seaplane
ψ'=Inclination of rudder to axis of hull
R="Directional radius" for full-size seaplane.

$$= \frac{57.3}{W} \times \frac{\Delta M}{\Delta \psi'} \text{ feet per degree.}$$

For 40 m.p.h $\frac{\Delta M}{\Delta \psi'} = 175$ R=0.743
"   65   " $= 462$ R=1.952

Curve corrected for asymmetry

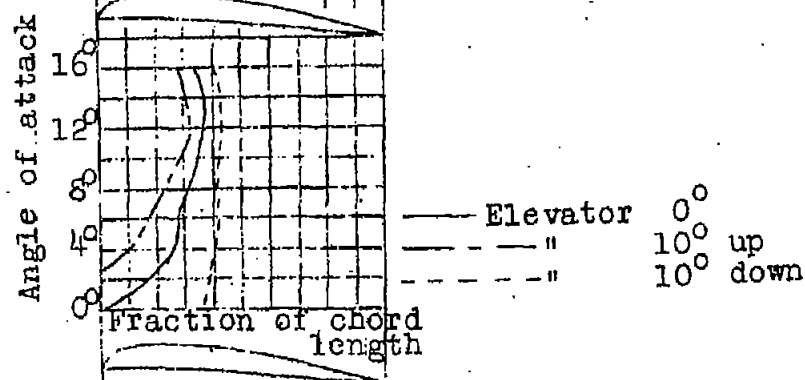R.A.F.6 Aerofoil, chord 4° to thrust line.

Dihedral = $1\frac{1}{2}^{c}$

Altered fin.

Reference axis for pitching moments is 38% of chord length below thrust line and 35% of chord length aft of leading edge.

$2\frac{1}{2}^{o}$

Vector for 6° angle of attack, elevator 10° up

2°   14°   Vector for 6° angle of attack, elevator 10° down.
0°   -12
      16°

Fig.12. Line of resultant air force at 40 m.p.h.

Angle of attack

16
12
8
4
0

Fraction of chord length

———— Elevator 0°
— — — " 10° up
— · — · — " 10° down

Center of pressure travel along horizontal plane through C.G. for fixed pitch axis shown.
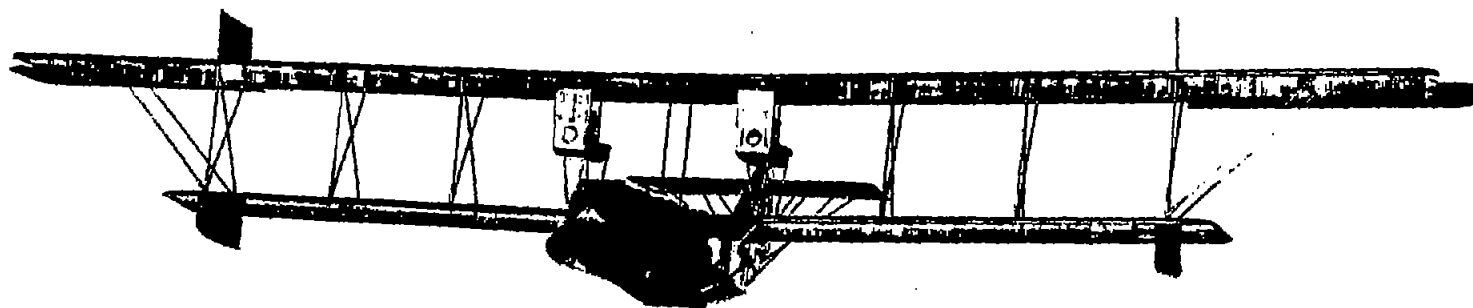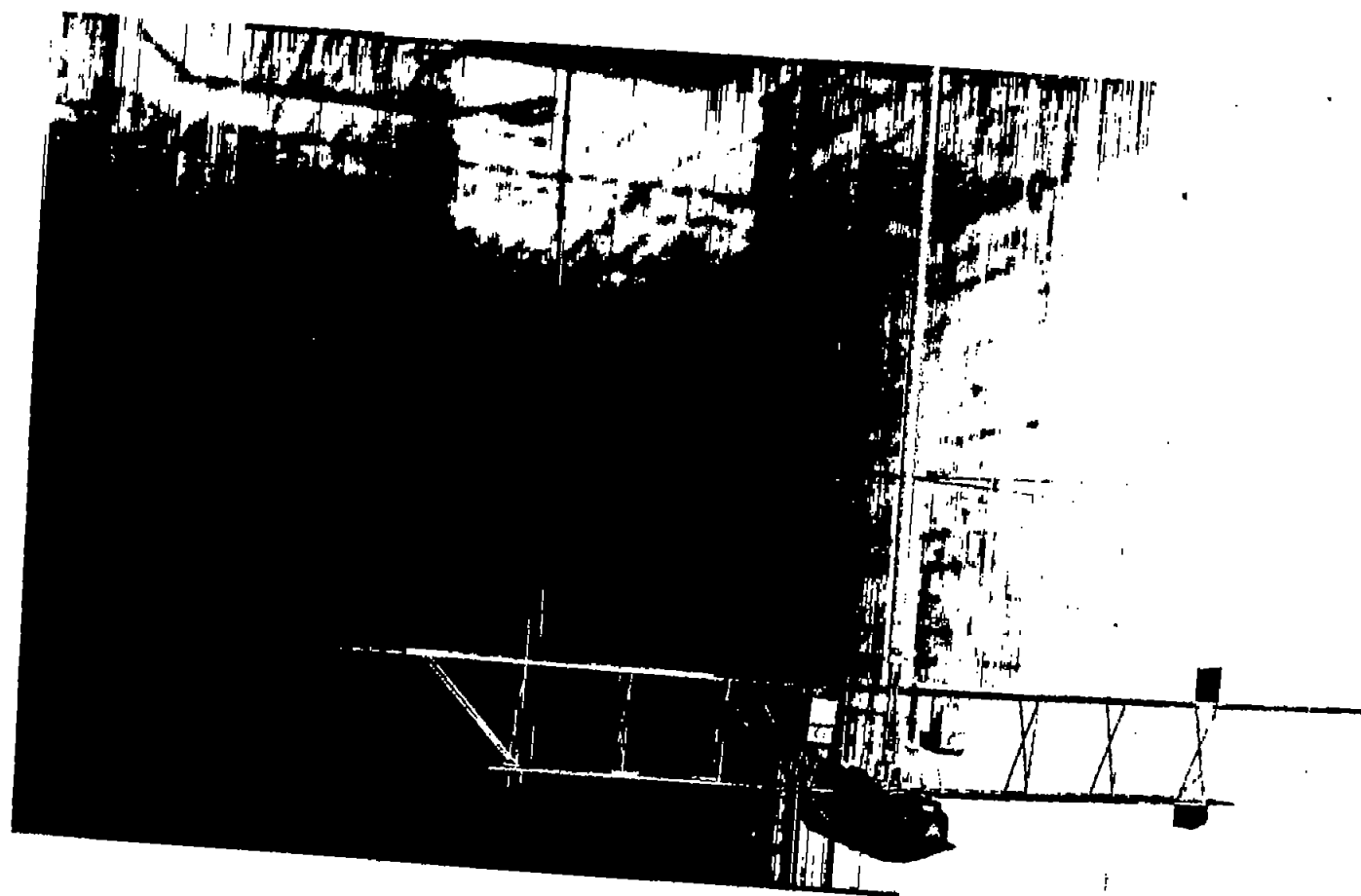
Fig. 13

7748.A.S.
Fig. 14

APPENDIX.

Comments on the Preceding Tests.

By Max M. Munk.

The results of the preceding tests are very suitable for checking a formula or rather the existing method for the calculation of the moment produced by the displacement of, for instance, the elevator. This formula would be:

$$(1) \qquad \frac{L}{\epsilon \, S \, q} + \frac{L}{\epsilon \, S \, q} \times \frac{S}{b^2} \; \frac{57.3}{\pi} = K$$

wherein

L   the lift produced by a displacement

ε   angle of displacement

S   the area of the elevator

b   the greatest span of the elevator or tail plane

q   the dynamical pressure of the speed as given by the Pitot tube.

K   a coefficient, which is not variable to a great degree, is about 1.3 for the usual ratio of the elevator and tail plane area.

The meaning of the formula is as follows: The first term is the lift per unit of elevator area, dynamical pressure and displacement. 57.3 L/b q is the decrease of the induced angle of attack in degrees which multiplied by 0.1 S q gives the corresponding lift; while the second term gives this lift per unit of the area, dynamic pressure and displacement. The left side thus represents the entire result of the displacement, the second term is the part neutralized subsequently by the aerodynamical induction.

In order to check up this formula I proceed now to calculate
the factor K from the results of the preceding tests. I divide
the moments obtained from respective arms, by the dynamic pres-
sure, the area and the displacement. To this I add the change
of the induced angle of attack multiplied by 0.1. The sum is the
coefficient K. I begin with the elevator and refer to the full-
sized seaplane.

A 20° displacement of the elevator produced a pitching mo-
ment of 7250 ft. lbs., the arm being 16.2 ft., the elevator area
55.3 sq.ft., and the dynamical pressure 4.1 lbs.sq.ft. The
product of area, arm and dynamic pressure is 3670 lbs. ft. The
increase of the moment per 1° is 362 ft. lbs., hence the increase
of the corresponding lift coefficient with reference to the ele-
vator area is

$$362/3670 = 0.099$$

(which is the first term of equation 1)

The span of the elevator is 19.5 ft., hence the area ratio

$$area/span^2 = 55.3/19.5^2 = 0.121$$

(giving the second term of the equation)

and the induced angle of attack for the lift coefficient 0.099 is

$$0.099 . 0.121 . 57.3/\pi = 0.22°$$

an angle which corresponds to a lift coefficient ten times as
as small, that is, 0.022. Hence the real effect is so much
greater, that is

$$0.099 + 0.022 = 0.121$$

and the theory supposes this coefficient to be constant for each ratio elevator/tail-plane and to be in the neighborhood of the obtained value for the present ratio.

The rolling moment, as produced by the displacement of the ailerons, can be treated similarly. The product of area, arm, and dynamic pressure is now 20,400 lbs./$\frac{ft.}{}$ for the full-sized seaplane and the produced moment per $1°$ displacement is 2,000 lbs. ft., therefore:

$$C_L = 0.1 \text{ per } 1°$$

The ratio of the aileron chord to the wing chord is about the same as with the elevator and the effect of the induction ought to increase this coefficient to about 0.12 as before. This effect however cannot be calculated as easily as before, but on the contrary could be determined by model tests similar to the present one. In this particular case the space between the aileron and the wing was particularly great, thus decreasing the aileron effect, and that is the reason why this test is not well fitted for this calculation. It can be seen, however, that the obtained value is not very far from the expected value.

The yawing moment is produced by a rudder area of 33.5 sq.ft. and the product of this area by the arm and the dynamic pressure is 2230 lbs. ft. The moment corresponding to $1°$ displacement of the rudder is 160 lbs. ft., giving the first term a value of

$$C_L = 0.072$$

The vertical span of the tail unit can be considered to be about

10 ft., giving an area ratio

$$33.5/10 = 0.335.$$

The induced lift coefficient for 0.072 is now

$$57.3 \cdot 0.1 \cdot 0.072 \cdot 0.335/\pi = 0.054$$

increasing the apparent effect to the real effect

$$0.072 + 0.054 = 0.126$$

This is approximately the same value again as with the elevator.

The yawing moment produced by a yawing angle is a function of the shape of the entire seaplane and cannot be calculated as before. This also holds true for the increase of the moment as produced by the increase of the tail plane area, as the effective angle of attack is unknown. In the present case the increase is the same as if the effective angle of attack is only 38% of the yawing angle. It is known however from experience that the physical law between an increase of tail plane and the produced effect is very irregular and an increase of the area can even result in a decrease of the stability. The phenomenon is much dominated by the viscosity of the air, and such model tests which are not at full scale with respect to viscosity must be regarded as doubtful.

The effect of the displacement of the controlling surfaces as observed by this model test well agrees with the computation and hence these tests augment the confidence in these modern methods of aerodynamic computation.